

# BORON

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Boron produced domestically during 2002 totaled 1.05 million metric tons (Mt) valued at \$513 million (table 1). The boron oxide content was 518,000 metric tons (t). The most common minerals of commercial importance in the United States were colemanite, kernite, tincal, and ulexite (table 2). Boron compounds and minerals were produced by surface and underground mining, in situ, and from brine. U.S. consumption of minerals and compounds amounted to 359,000 t of boron oxide (table 3). Boron products are priced and sold based on the boron oxide content, which varies by ore and compound, and on the absence or presence of sodium and calcium (table 4). Boron exports of boric acid and sodium borate totaled 234,000 t (table 5). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 6). Turkey and the United States were the world's largest producers of boron minerals (table 7).

The glass industry, which remained the largest domestic market for boron production in 2002, accounted for 78% of boron consumption. Insulation-grade glass fibers accounted for an estimated 50% of domestic consumption; textile-grade glass fibers, 19%; boron sold to distributors, 8%; soaps and detergents, 6%; borosilicate glasses, 5%; enamels, frits, and glazes, 4%; and other uses, 8%.

## Legislation and Government Programs

In January 2001, the Secretary of Transportation announced the selection of the Baltimore, MD, to Washington, DC, and the Pittsburgh, PA, projects as the two magnetic levitation (maglev) projects for further consideration for Federal construction funding. Maglev is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle on a specially designed guideway. Boron is used in the superconducting and other high-intensity magnets in this system. By using state-of-the-art electric power and control systems, the maglev system would reduce the need for many mechanical parts, thereby minimizing resistance and permitting improved acceleration compared with conventional modes of transportation and cruising speeds of about 385 kilometers per hour (240 miles per hour) or more. The Baltimore, MD, to Washington, DC, project was a 25-kilometer (km) (40-mile) project linking Camden Yard in Baltimore (a sports complex and center for recreation and tourism) and Baltimore-Washington International Airport to Union Station in Washington, DC. This project has been under study since 1994. The project sponsors saw this project to provide rapid transportation between sports venues as a means to winning a bid for the 2012 Olympic games. The Pittsburgh, PA, project was a 29-km (47-mile) project linking Pittsburgh Airport to Pittsburgh and its eastern suburbs. The project has been under study since 1990 and is backed by a coalition of State and local agencies, labor unions, and members of the Pittsburgh community. Maglev Inc., the organization that would develop the project, sees it as not only a transportation system for commuters and air travelers but also as a platform for bringing the precision steel-fabrication technology that will be used in the construction of the guideway to the Pittsburgh region. The two project teams will share about \$14.2 million in Federal funding, to be matched by \$7.1 million locally to refine proposed plans, estimates of ridership and revenues, and environmental analysis and to secure financial commitments. A single project was to be chosen for construction in the spring of 2003 (Federal Railroad Administration, 2001§).

A public-private partnership of the U.S. Department of Energy (DOE) was expected to spend about \$150 million to develop a hydrogen fuel cell. The funding is good news for boric acid producers. Millennium Cell Inc. of Eatontown, NJ, invented and developed a proprietary process called "hydrogen on demand." In the process, the energy potential is carried in the chemical bonds, which in the presence of a proprietary catalyst produces electricity. The fuel is emission-free at the time of use, and the only byproducts are water and sodium metaborate. The advantage of sodium borohydride compared with conventional catalysts is that it can easily be stored and transported in lightweight plastic tanks at normal temperatures and pressures and is neither poisonous, flammable, or explosive (O'Driscoll, 2002).

In July 1960, four B-25 bombers crashed while dropping borates on forest fires near Magic Mountain in southern California. The U.S. Department of Agriculture's Forest Service banned B-25s from fire-suppression operations. In 1985, one of the remaining B-25s landed at Dulles International Airport in northern Virginia and became part of the Smithsonian Institution's National Air and Space Museum exhibit. The aircraft will be on display at the new Udvar-Hazy Center opening in 2003 (Smithsonian Institution, 2002§).

The Nuclear Regulatory Commission (NRC) reported that cracks in the vessel-head pressure nozzles at the Davis Besse nuclear power station, Oak Harbor, Ohio, led to leakage of water containing borates from the reactor's primary coolant system. The formation of boric acid, which is corrosive to carbon steel, dissolved 6 inches of carbon steel that encased the core of the reactor. The result could have been a loss-of-coolant accident and possibly a reactor-core meltdown. One-half inch of stainless steel cladding was all that prevented a catastrophic disaster (Johnson, 2003).

High-level nuclear waste that has been stored at 103 operating nuclear reactor powerplants is planned to be vitrified using boron compounds and transported to Yucca Mountain, NV, for storage. The DOE applied for a license for the new facility from the U.S. Nuclear Regulatory Commission, a process that could take up to 5 years. None of the 70,000 t of waste would be moved before the

facility is completed in 2010. A program for the safe transportation of the waste could be ready by 2003. About 3,200 metric tons per year (t/yr) of waste is to be shipped (Loft, 2002).

In January 2002, the U.S. Consumer Product Safety Commission (CPSC) denied the 1994 request of the National Association of the State Fire Marshals to adopt the existing California Bureau of Home Furnishings and Thermal Insulation Code for residential upholstered furniture. A meeting was held June 18-19 for CPSC staff and interested members of the public to discuss options for addressing upholstered furniture flammability. Presentations at the meeting covered recent industry activities, technical data, and innovations related to the small open flame performance of upholstered furniture. The CPSC staff was making revisions to its draft small open flame standard as a result of the comments presented at the meeting. The California standard was issued in 1975 and did not contain information on the health effects from exposure to chemical fabric treatments. CPSC staff began working with the EPA's Office of Pollution Prevention and Toxics to develop a significant new use rule for fire retardant chemicals used in fabric treatments to meet a new flammability standard for upholstered furniture (U.S. Consumer Product Safety Commission, 2003§).

## Production

Domestic data for boron were derived by the U.S. Geological Survey from a voluntary survey of four U.S. operations. The majority of boron production continued to be from Kern County, CA, with the balance from San Bernardino and Inyo Counties, CA. All four operations to which a survey request was sent responded, representing 100% of the total boron produced (tables 1, 3).

More than 200 minerals contain boric oxide, but only a few were of commercial significance (table 2). Four minerals comprised almost 90% of the borates used by industry worldwide; they are the sodium borates borax and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite. These minerals were extracted primarily in California and Turkey and to a lesser extent in Argentina, Bolivia, Chile, China, and Peru.

American Borate Co. mined small amounts of colemanite and ulexite-probertite underground at the Billie Mine in Death Valley, CA. The ore was transported to Lathrop Well, NV, for processing. Storage and grinding facilities were at Dunn, CA.

Fort Cady Minerals Corp. used an in situ process near Hector, CA, to produce a product that contains 48% boron oxide. Because the product is chemically precipitated, this product has advantages in the consistency of its chemical composition, namely, high boron oxide content, low impurities, and a consistent physical size. The product contained 25% calcium oxide, 0.8% sulfur, 0.1% chloride, 0.08% iron, and less than 1 part per million arsenic. In situ extraction required that wells be drilled 427 meters (m) (1,400 feet) into the ore body. A solution of dilute sulfuric acid was injected into wells in the borate ore. The boron-enriched solution was pumped to the surface and then reacted with lime to precipitate a pure calcium borate product.

IMC Chemicals (IMCC) operated the Trona and Westend plants at Searles Lake in San Bernardino County. IMCC produced refined sodium borate and boric acid from the mineral-rich lake brines. A series of pumps circulated brines in the upper unit salt layer of the lake to increase the borax grade to a theoretical 1.45%. The brine was processed at the Westend plant to remove the sodium borate and then circulated back to the upper salt layer.

IMCC applied for a temporary royalty rate reduction to the Bureau of Land Management to 2% of the gross value for the sodium and potassium compounds, which is the minimum royalty rate allowed by regulation, from 5% of the gross value. The reduction is based on the fact that lease operating costs exceed lease production revenue. Factors that contributed to the request were high environmental costs, high energy costs, declining prices, and a decline in the U.S. economy since the events of September 11, 2001. IMCC produces approximately 1.5 million metric tons per year (Mt/yr) of borax, soda ash, and related products from 30 Federal mineral leases and from private land owned by IMCC. The company pays about \$3.5 million per year in mineral royalties to the U.S. Department of the Interior's (DOI) Minerals Management Service (MMS). The MMS puts one-half the royalties in the DOI's General Treasury and returns the other one-half to the State of California for the benefit of local public education. Of the one-half that is returned to the State, 85% goes to the direct benefit of the Trona Unified School District, and the other 15%, into the community college system (Newsbytes, 2002§).

U.S. Borax, Inc. (a wholly owned subsidiary of London, United Kingdom-based, Rio Tinto plc) mined borate ores at Boron, CA, by open pit methods, and transported the ores to the surface by trucks. The ore was processed into sodium borate or boric-acid products in the refinery complex adjacent to the mine. An onsite plant also produced anhydrous sodium borate and boric oxide. Refinery products were shipped by railcar or truck to North American customers or to the U.S. Borax Wilmington, CA, facility at the Port of Los Angeles for international distribution. In addition to its refinery and shipping terminal in Wilmington, U.S. Borax has its global headquarters in Valencia, CA, and its Owens Lake trona mine supplies raw material to the Boron, CA, refinery. Multiyear labor agreements that will provide additional operational flexibility and efficiency were negotiated at U.S. Borax's U.S. operations. U.S. Borax reported achieving a 12% increase in boric-acid-plant productivity by equipment upgrades and maintenance improvements at the Boron plant. Fresh water usage was reduced by 7% (Taylor, 2003). U.S. Borax's Owens Lake operation allowed the company to ensure control of the trona supply used in the borate refining process. Trona provided a cost-effective source of carbonates, which helped reduce scaling in the processing equipment.

In April 2002, the Industrial Minerals Association-North America (IMA-NA) held its inaugural meeting to adopt bylaws, elect a board of directors, organize standing committees, and approve a budget. U.S. Borax was a member of the IMA-NA soda ash and borates section. The organization is structured to enable the industrial minerals industry of North America to coordinate efforts for handling issues of common concern. Through a structure of standing committees and task forces, the association addresses such issues as government affairs, safety and health, environment, operations, and engineering (Industrial Minerals Association-North America, 2003§).

## Environment

The 2001 Rio Tinto Borax social and environment report described efforts to measure and improve how company practices sustainability and how its products contribute to a sustainable future. The wide range of issues involved in supplying nearly one-half the world's demand for refined borates called for a comprehensive system to ensure that operations and products contribute to sustainable development. Borax believed its contribution to sustainable development to be that its operations have a low environmental impact and make positive social contributions; that its borate products enhance standards of living and contribute to economic development; and that borates measure up favorably to most substitute products. To aid the mining industry in progressing toward sustainable development, the IMA-NA was formed as an industry association. In addition, a number of the world's largest mining companies established the Global Mining Initiative as a case for mining as a positive factor towards sustainable development. The three principal goals adopted to guide Rio Tinto are as follows: economic, environmental, and social. These goals require maximizing use of resources while minimizing environmental impacts of the operation; protecting the safety and health of employees, contractors, neighboring communities, and the public by prevention; raising safety consciousness and instituting systems to make the workplace safer; and enhancing the human potential and well-being of communities and employees by measuring and improving quality of life now and beyond the life of the operation. Sustainable development required Borax to assess and address the principal goals and to involve experts outside the company in the process (U.S. Borax, Inc., 2002).

## Consumption

U.S. Borax joined with Luzenac Group, the world's leading talc producer owned by Rio Tinto, to provide enhanced borate technical service to the North American pulp and paper industry (Keefe, 2002§). Boron-based autocausticizing was a cost-effective technology to recover kraft-pulping chemicals. The technology can be used to supply either part or all the sodium hydroxide requirements of the kraft process, supplementing or replacing the lime cycle. The kraft pulping process is the dominant technology for pulping wood in the production of kraft paper. The regeneration of sodium hydroxide by causticizing with calcium hydroxide produces calcium carbonate. Sodium metaborate is a favorable autocausticizing agent; for example, it forms caustic directly without the use of the lime cycle (U.S. Department of Energy, 2001§).

A move away from perborate laundry cleaners in Europe and a move to percarbonate cleaners have resulted in the Solvay Interox division of Solvay America, Inc. (a member of Solvay Group) closing its Deer Park, TX, sodium perborate plant at the beginning of 2002 and building a second sodium percarbonate plant in Deer Park (Chemical & Engineering News, 2003a).

Glass-fiber thermal insulation, primarily used in new construction, was a large end use for borates and was the principal insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, fiberglass traps and holds air. Typically, between 4% and 5% of boron oxide is incorporated in its formulation to aid melting, to inhibit devitrification, and to improve the aqueous durability of the finished product.

Borates also were used in a range of products made from high-tensile-strength glass fiber materials. The process of producing the glass fiber uses a borosilicate (E-glass) formulation that is continuously drawn through platinum alloy bushings into continuous 9- to 20-micrometer diameter filaments. Calcium aluminoborosilicate, E-glass, or textile fiberglass typically contains between 6% and 10% boron oxide.

Boron is 1 of 16 nutrients essential to all plants. It is essential to plant growth and can be applied as a spray and incorporated in fertilizer, herbicides, and irrigation water. Boron applied in May and June can be combined with calcium. For early season apples, boron can be applied post-harvest to provide adequate nutrition as buds begin to develop. In 2001, 5,690 t (6,272 short tons) of boron micronutrients was applied on crops compared with 13,400 t (14,769 short tons) in 2000. The largest U.S. region of use was in the Pacific, which used 1,830 t (2,020 short tons) (Terry and Kirby, 2001, p. 37; 2002, p. 37).

Dongguan Sumitoku-Super Electric Co. (DSSE) of China started production of Neomas neodymium-iron-boron magnets, using rare-earth materials sourced in China, and sintered material imported from Sumitomo Special Metals Co. DSSE was 100% owned by Sumitok-Super-High-Tech Co. Ltd. (Hong Kong) [a manufacturing joint venture between Sumitomo Special Metals Co. (Japan) (60%) and Super Electronic Co. (Taiwan) (40%)] (Industrial Minerals, 2002b).

Englehard Corp.'s Firemist™ is a patented borosilicate-based pigment with brilliant color and glittering effects. These advanced pigments were specially formulated to outperform traditional pearlescent pigments in brightness, chroma, color purity, reflectivity, and transparency. The smooth surface and larger particle size create a brilliant, starlike glitter, and blends of pigment grades create true multicolor effects (individual colors come through because the pigments' exceptional transparency and chroma overcome the addition effects that gray out normal pearls). The feeling of depth created by borosilicate flakes in coatings and plastics applications is beyond that possible with mica-based pearls because the borosilicate flakes promote light penetration. Borosilicate-based pigments are used on automotive trim applications, such as powder coatings or plastic and leather coatings, and can be used in many other applications, as well (Thayer, 2002).

## Transportation

Almost all U.S. Borax bulk product was shipped in North America by rail. The Boron Mine is served solely by the Burlington Northern Santa Fe railroad. In order to connect to another rail line, a transload was set up in Cantil, CA, about 64 km (40 miles)

northwest of Boron, which is served by the Union Pacific railroad. Trucks of product from Boron are driven to Cantil and loaded into dedicated railcars to be shipped to customers.

Ocean transport was from the Port of Wilmington, CA, where U.S. Borax had the only remaining privately owned berth in the harbor. It ranked as the largest exporter of high-value dry bulk products and among the top 10 shippers of ocean containers out of the Ports of Los Angeles and Long Beach, CA. In 2001, the equivalent of more than 8,000 6.1-m (20-foot) containers was shipped to nearly 100 countries (Docks, 2002).

Products destined for Europe were shipped from the bulk terminal in Wilmington, CA, to a company-owned facility in the Port of Rotterdam, Netherlands, using handymax vessels of about 45,000-short-ton deadweight capacity. The vessels have been supplied by the Japanese shipping company "K" for more than 20 years. Holds in smaller vessels also are used to transport bulk borates to company facilities in Spain and to contracted warehouses in Monfalcone, Italy, and Port Klang, Malaysia. Borax Group also maintains secondary stock points that include Austria, Germany, Norway, the Republic of Korea, Taiwan, and Ukraine (Docks, 2002).

Antwerp, Belgium, which had the most central port location in Europe, had access to 188 major European cities. The industrial minerals market in Europe was characterized by high volumes of imported materials, mostly forwarded through the industrialized areas of Belgium, France, Germany, and the Netherlands for destinations in Central Europe, such as Austria, the Czech Republic, and Slovenia. The decision to import material was based on the geographic location, the range of service needed, and prices.

U.S. Borax used barges to ship borates from Rotterdam, to customers in Belgium, Eastern Europe, France, Germany, and countries even farther away. Barges were the most efficient and reliable method of transporting goods in Europe, which have a 25,000-km network of navigable canals and rivers. Most of the large industrial areas could be reached by barge on waterways that link parts of the North, the Baltic, the Black, and the Mediterranean Seas and the Atlantic Ocean. In 1992, the 170-km canal linking the Main River to the Danube River was opened in Germany.

The Trona railway, connected to the Southern Pacific railroad between Trona and Searles Station, provided a dedicated line with access to the national rail systems for the borate and soda ash markets. Cross-country rail shipments are more cost effective than the use of U.S. flag shipping lines, the use of which is required by the Merchant Marine Act of 1920, or the Jones Act, for shipping on all U.S. waterways and goods moved between U.S. ports.

## Prices

Prices of boron minerals and compounds produced in Argentina, Brazil, Turkey, and the United States are listed in table 4.

Adding borates to ceramic tile bodies can reduce firing-cycle and temperature requirements, lowering the energy needed for manufacturing tile, thus lowering costs. Borates increased the dry mechanical strength of unfired tiles between 30% and 80%, thereby lowering handling losses and saving money, which can be passed on to consumers in lower prices (Chemical Market Reporter, 2003).

## World Review

World consumption of boron was reported to have doubled since 1970 (Roskill Information Services, Ltd., 2002). In 2001, world borate consumption reached about 1.5 Mt. The North American glass industry used about 44% of worldwide boron consumption during 2001. Insulation-grade fiberglass was the largest end use. Detergents and soaps make up the second largest application.

The European detergent market accounted for more than 78% of the 240,000 t/yr of world sodium borate consumption. Western Europe consumes about 185,000 t/yr of sodium borate, and the United States consumes about 23,000 t/yr of boron oxide in the form of sodium perborate (Mining Engineering, 2002). Future changes include stricter regulations for boron levels in drinking water in the European Union by 2013 that would affect the use of boron in detergents.

**Argentina.**—Borax Argentina S.A. (a subsidiary of Rio Tinto plc) was the country's leading producer of borates and exported large quantities to the United States (tables 6 and 7). Borax Argentina mined borates at three deposits—Tincalayu and Sijes in Salta Province and Porvenir in Jujuy Province—and produces about 100,000 t/yr of borates. Previous investment of \$2.4 million upgraded equipment including new furnaces, centrifuges, and a magnetic concentration plant (Taylor, 2003). The Tincalayu Mine, originally developed in 1976, was Argentina's largest open pit operation and measured 1.5 km long, 500 m wide, and 100 m deep. The clay overburden averages 50 m and typically overlies 30 to 40 m of ore. About 100,000 t/yr of ore was trucked from the mine to a rail terminal at Packets, 120 km north of Tincalayu, and loaded on trains of 11 cars, each with a 30-t capacity. A drilling program was completed to verify a new borate resource (Industrial Minerals, 2002a). Rio Tinto Borax invested \$2.6 million to establish a new boric-acid plant near the Campo Quijano, Salta, refinery. Construction began in August 2002, and boric-acid production was expected to begin in 2003 using tailing from the company's ulexite concentration operation as feedstock.

U.S. Borax's Salar del Rincon project consisted of a brine of dissolved salts with a high concentration of borate salts. The 500-square-kilometer (km<sup>2</sup>) playa lake is in northwestern Argentina at an altitude of 3,700 m. The area of interest was covered by 53 contiguous mining leases covering 410 km<sup>2</sup>. The project was served by national roads and the trans-Andean railline to Chile, with a parallel network of power and gas lines (Terence Willsted & Associates, 2002, p. 2).

**Bolivia.**—Química del Bórax (Quiborax), Rio Grande ulexite deposit had ore grades of 32% to 36% boron oxide and very low arsenic levels. About 25,000 t/yr of ulexite was extracted. The Capina ulexite deposit of 25% to 32% boron oxide was not being mined, but has reserves of 10 Mt of low-arsenic ulexite. Quiborax also had a 35,000-t/yr boric acid plant at El Aguila, 60 km from Arica (Taylor, 2003).

**Chile.**—Quiborax invested \$10 million in recent years in modern technology and plant automation. The company intended to invest \$7 million more between 2003 and 2008. Quiborax owned the Surire Ulexite deposit in northern Chile with reserves of several million metric tons of ulexite that contained between 25% and 32% boron oxide. Production capacity was 2,000 metric tons per day (t/d) or 350,000 t/yr during the 7-month production period (Taylor, 2003).

**Italy.**—Societa Chimica Larderello closed its technical-grade boric-acid capacity that was estimated to be between 50,000 t/yr and 60,000 t/yr during 2002 (Taylor, 2003). Boric acid from Russia is being used to feed the purified-grade boric-acid facility (Milan Popovic, written comm., 2002).

**Turkey.**—Government-owned Eti Bor (a subsidiary of Eti Holding, Inc., formerly known as Eti Bank) announced an expansion of 15,000 t/yr at the Bandirma boric-acid facility in 2001 with its capacity reaching 60,000 t/yr in 2002. A 100,000-t/yr boric-acid plant also was being constructed at Emet and was expected to be operational in 2004. A 60,000-t/yr anhydrous-borax plant produced small amounts in 1996. Privatization of the Turkish borate market would be difficult because of the market's overcapacity; however, if operated to capacity, the plants could lower prices. A solution to the overcapacity would be the construction of specialty chemical plants (Buehler, 2003).

The Turkish Government planned to establish a Boron Research Institute to develop Turkey's exports of processed boron. The largest demand for boron minerals and chemicals is in vitreous applications (40%), ceramic industry (15%), and the detergent bleach industry (10%). About 7% of production is consumed in the domestic market. The balance was exported, with 40% to Europe, and 25%, to North America (Schmidt-Whitely and Loehman, 2003).

Total boron reserves that included "apparent, likely, and possible" were estimated to be 1 billion metric tons of boron oxide. Eti Holding has a monopoly on boron in Turkey, and Eti Holding and U.S. Borax have an oligopoly in the international market. A new boric-acid plant was under construction in Kutahya Emet, and Eti planned for the plant to begin production in 2003; the new construction will increase capacity to 185,000 t/yr from 85,000 t/yr. A third derivatives plant with a capacity of 160,000 t/yr was established next to the plants in Eskisehir and Kirka; it has a capacity of 320,000 t/yr. Upon completion of current construction and at full capacity, Eti Holding's boron minerals capacity will increase by 260,000 t/yr to 800,000 t/yr. Feasibility studies were being conducted on a fourth derivatives plant with capacity of 240,000 t/yr. The fact that boron minerals are not fully utilized was attributed to a lack of science and technology policy (Gozler, 2002).

## Current Research and Technology

The U.S. Department of Energy's Ames Laboratory in Ames, IA, studied a boron-aluminum-magnesium alloy with a hardness nearly equal to that of diamond as a replacement on utility tools. Diamond wears quickly when cutting steel owing to a chemical reaction between the carbon in the diamond and the iron in the workpiece. The new alloy cuts without getting as hot as existing utility tools reportedly because of the fine grain size and the complex crystal structure (Advanced Materials & Processes, 2002).

Ionic liquids comprising a boron compound could prove useful for the fabrication and operation of polymer electrochemical devices. A team of scientists at Santa Fe Science & Technology Inc., Santa Fe, NM, the University of Wollongong, New South Wales, Australia, and Monash University, Victoria, Australia, tested polymer fiber- and yarn-based electrochemical mechanical actuators, tube actuators, and high-performance electrochromic windows and numeric displays; the tests demonstrated that polymers exhibited faster cycle switching speeds than devices based on aqueous, organic, gel, or polymer electrolytes (Chemical & Engineering News, 2002c).

A diboronic ester compound that contains boron was used as a catalyst in a solution processing method for flat screen, full-color organic light emitting diode (OLED) displays. The process combined polymer-based OLED device manufacturing by solution processing with well-established photolithographic patterning process. The technology could be utilized for fabrication of true-color matrix displays offering patterning of colors at high resolution (Freemantle, 2003).

Boron-neutron capture therapy (BNCT) selectively delivered boron-10 nuclei to tumor cells. BNCT can be used in the treatment of malignant brain tumors. When the boron-10 captures neutrons from radiation, helium and lithium ions form that result in cell death in the surrounding tissue. A new compound was designed to deliver therapeutic amounts of a boron-rich compound to tumor cells that can be selectively absorbed by tumor cells, thus increasing the capture of neutrons and resulting in the death of tumor cells (Freemantle, 2002).

An improved one-pot synthesis of an aqua-carbonyl complex used a boron reagent to furnish technetium complexes. In these complexes, the metal is coordinated to five carbons and three carbonyl groups. The complexes are of interest for radiopharmaceutical purposes because they can be made to target molecules, such as a tumor-specific peptide or a small molecule that binds to a central nervous system receptor. The complex can ferry the radioactive material across the blood-brain barrier (Hiteman, 2002).

A new technique used boron to synthesize aminoacid derivatives. The technique results in a transfer of a side chain from the organoborane to another compound with reactions increasing from 54% to 95% efficiency. The technique is to be used to prepare optically active aminoacids with multiple centers (Chemical & Engineering News, 2002a).

Manganese and ruthenium complexes were made using a boron ligand, a six member aromatic ring with one phosphorus atom and one boron atom. The new compound is being investigated as a catalyst (Chemical & Engineering News, 2003b).

Thin films of magnesium diboride ( $\text{MgB}_2$ ) were produced that could be used as a more efficient generation of superconducting electronic devices.  $\text{MgB}_2$ -based circuits would operate between 20 and 25 K, which is achievable using roughly one-tenth the mass and power consumption required for a 4.2 K cooler used with current niobium-based superconductors (Dagani, 2002).

Borane, a pyrophoric gas, is an important reagent in the fine-chemicals and pharmaceutical industries. A fluorine sulfide-borane that is nonflammable and nonvolatile can be used in many reactions, and the sulfide can be recovered from the fluorine phase, recharged with borane, and reused (Chemical & Engineering News, 2002b).

A Chicago company named Life Gem has been offering blue diamonds made from the carbon extracted from the ash derived from cremation of the beloved. The diamonds are blue because of trace amounts of boron contained in the bone. The process takes about 16 weeks, and diamonds can be produced from animal and human remains. Typically carbon in the body is incinerated and turned into gas during the process of cremation. LifeGem captures the carbon before becoming gas. The carbon is purified and turned into graphite by heating at 6,000° F. The graphite is sent to a laboratory in Russia where about 5 grams of graphite yields a one-quarter-carat diamond (Copeland, 2002).

Research by biochemist Joseph Nagyvary discovered that Stradivari and Guarneri violin wood had been treated with a mixture rich in borax. Borax acts as a cross-linking agent, binding different molecules together with a gelatinous web and filling tiny pores in the wood (Borax Pioneer, 2002).

Boron received attention as a critical parameter for optimizing water purification processes and as a potential source of contamination in susceptible manufacturing processes. Because boron occurs naturally in the environment and is also introduced by industrial discharges, it is ubiquitous in water supplies worldwide. Ionics Instrument Business Group, Boulder, CO, designed an anion-cation resin where boron and other impurities are removed and continuously tested. A proprietary reagent produces a highly ionized complex that allows for very sensitive measurements of boron at extremely low levels of boron (Dunn, 2002).

## Outlook

The boron industry is directly affected by the health of the glass industry. Sales of boron for glass consumption represented 78% of domestic demand in 2002 and, including borosilicate glass, enamels, insulation-grade glass fibers, and textile-grade glass fibers, increased by 4% in 2002. Very low growth in sales of boron to these markets probably will persist as long as the U.S. economy continues to stagnate. The soap and detergent market remained flat.

Imports of boron chemicals from Turkey are expected to grow as manufactured Turkish boron derivatives increase and supplies of boron minerals diminish from the market. New plants for boric acid and sodium borate that are to come onstream may have a negative impact on prices of boron derivatives.

New technology could create large demands for boron chemicals. New uses in fuel cells for automobiles have a potential for creating a strong demand. A new process in paper mills that takes advantage of boron chemicals being recycled for reuse can lower efforts needed to meet environmental requirements and lower production costs.

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TABLE 1  
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS<sup>1</sup>

(Thousand metric tons and thousand dollars)

	1998	1999	2000	2001	2002
United States:					
Sold or used by producers:					
Quantity:					
Gross weight <sup>2</sup>	1,170	1,220	1,070	1,050	1,050
Boron oxide (B <sub>2</sub> O <sub>3</sub> ) content	587	618	546	536	518
Value	486,000	630,000	557,000	506,000	513,000
Exports: <sup>3</sup>					
Boric acid: <sup>4</sup>					
Quantity	106	107	119	85	84
Value	54,600	56,700	64,400	47,000	44,600
Sodium borates:					
Quantity	453	370	413	221	150
Value	146,000	180,000	136,000	91,700	63,100
Imports for consumption:					
Borax:					
Quantity <sup>3</sup>	14	8	1	1	( <sup>5</sup> )
Value	5,160	2,840	716	642	94
Boric acid:					
Quantity <sup>3</sup>	23	30	39	56	49
Value	12,500	14,000	17,500	21,700	18,400
Colemanite:					
Quantity <sup>6</sup>	47	42	26	35	32
Value	13,900	13,100	7,410	9,790	8,960
Ulexite:					
Quantity <sup>6</sup>	170	178	127	109	125
Value	34,000	35,700	31,800	21,800	25,000
Consumption, B <sub>2</sub> O <sub>3</sub> content	NA	416	360	347	359
World, production	4,570	4,460	4,600 <sup>r</sup>	4,740 <sup>r</sup>	4,610 <sup>e</sup>

<sup>e</sup>Estimated. <sup>r</sup>Revised. NA Not available.

<sup>1</sup>Data are rounded to no more than three significant digits.

<sup>2</sup>Minerals and compounds sold or used by producers, including actual mine production, and marketable products.

<sup>3</sup>Source: U.S. Census Bureau.

<sup>4</sup>Includes orthoboric and anhydrous boric acid. Harmonized Tariff Schedule of the United States codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.

<sup>5</sup>Less than 1/2 unit.

<sup>6</sup>Source: Journal of Commerce Port Import/Export Reporting Service.

TABLE 2  
BORON MINERALS OF COMMERCIAL IMPORTANCE

Mineral <sup>1</sup>	Boron oxide (B <sub>2</sub> O <sub>3</sub> )	
	Chemical composition	Weight percentage
Boracite (stassfurite)	Mg <sub>6</sub> B <sub>14</sub> O <sub>26</sub> Cl <sub>12</sub>	62.2
Colemanite	Ca <sub>2</sub> B <sub>6</sub> O <sub>11</sub> ·5H <sub>2</sub> O	50.8
Datolite	CaBSiO <sub>4</sub> OH	24.9
Hydroboracite	CaMgB <sub>6</sub> O <sub>11</sub> ·6H <sub>2</sub> O	50.5
Kernite (rasortie)	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·4H <sub>2</sub> O	51.0
Priceite (pandermite)	CaB <sub>10</sub> O <sub>19</sub> ·7H <sub>2</sub> O	49.8
Probertite (kramelite)	NaCaB <sub>3</sub> O <sub>9</sub> ·5H <sub>2</sub> O	49.6
Sassolite (natural boric acid)	H <sub>3</sub> BO <sub>3</sub>	56.3
Szaibelyite (ascharite)	MgBO <sub>2</sub> OH	41.4
Tincal (natural borax)	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O	36.5
Tincalconite (mohavite)	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·5H <sub>2</sub> O	47.8
Ulexite (boronatocalcite)	NaCaB <sub>5</sub> O <sub>9</sub> ·8H <sub>2</sub> O	43.0

<sup>1</sup>Parentheses include common names.

TABLE 3  
U.S. CONSUMPTION OF BORON MINERALS  
AND COMPOUNDS, BY END USE<sup>1,2</sup>

(Metric tons of boron oxide content)

End use	2002
Agriculture	12,900
Borosilicate glasses	19,300
Enamels, frits, glazes	12,700
Fire retardants:	
Cellulosic insulation	9,790
Other	1,480
Insulation-grade glass fibers	178,000
Metallurgy	39
Miscellaneous uses	6,010
Nuclear applications	--
Soaps and detergents	20,900
Sold to distributors, end use unknown	29,100
Textile-grade glass fibers	69,300
Total	359,000

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 4  
YEAREND PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON<sup>1</sup>

Product	Price, December 31, 2001	Price, December 31, 2002
Borax, technical, anhydrous, 99%, bulk, carload, works <sup>2</sup>	\$637	\$637
Borax, technical, anhydrous, 99%, bags, carload, works <sup>2</sup>	846	846
Borax, technical, granular, decahydrate, 99%, bags, carload, works <sup>2</sup>	378	340-380
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works <sup>2</sup>	374	374
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works <sup>2</sup>	426	426
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, work <sup>2</sup>	376	376
Boric acid, technical, granular, 99.9%, bags, carload, works <sup>2</sup>	834	834
Boric acid, technical, granular, 99.9%, bulk, carload, works <sup>2</sup>	788	788
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% boron oxide (B <sub>2</sub> O <sub>3</sub> ), 100-pound-bags, carlots <sup>2</sup>	1,996	1,996
Colemanite, Turkish, 42% B <sub>2</sub> O <sub>3</sub> , ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC <sup>3</sup>	270-290	270-290
Ulexite, Chilean, 38% B <sub>2</sub> O <sub>3</sub> , ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA <sup>e</sup>	200	200

<sup>e</sup>Estimated.

<sup>1</sup>U.S. free on board (f.o.b.) plant or port prices per metric ton of product. Other conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiation and/or somewhat different price quotations. Values have been rounded to the nearest dollar.

<sup>2</sup>Chemical Market Reporter, v. 261, no. 1, January 2002, p. 23; v. 263, no. 1, January 6, 2003.

<sup>3</sup>Industrial Minerals, no. 412, January 2002, p. 78; no. 424, January 2003, p. 66.

TABLE 5  
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY<sup>1</sup>

Country	2001			2002		
	Boric acid <sup>2</sup>		Sodium borates <sup>3</sup>	Boric acid <sup>2</sup>		Sodium borates <sup>3</sup>
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Australia	2,250	\$1,030	5,360	2,980	\$1,360	5,700
Belgium	--	--	7	--	--	531
Brazil	4,820	1,810	1,260	5,810	2,090	1,950
Canada	5,150	3,320	43,900	5,760	3,730	44,000
China	10,400	4,570	8,040	16,300	6,860	14,400
Colombia	138	139	2,310	173	119	2,130
France	114	75	12	115	53	7
Germany	200	135	8	178	264	13
Hong Kong	41	25	30	197	99	449
India	74	50	(4)	--	--	40
Indonesia	624	334	1,100	800	400	994
Israel	5	4	7	--	--	19
Italy	19	43	14,100	1	3	5,440
Japan	17,700	11,800	48,500	21,500	13,500	28,200
Korea, Republic of	11,800	6,290	13,400	12,400	5,950	11,600
Malaysia	2,950	1,570	2,420	1,470	1,030	5,080
Mexico	4,290	2,680	18,600	3,060	1,920	7,280
Netherlands	4,610	3,090	32,700	--	--	23
New Zealand	280	118	2,460	410	164	2,500
Philippines	38	27	1,300	29	18	1,010
Singapore	235	150	291	597	311	825
South Africa	169	113	4	--	--	(4)
Spain	3,750	1,420	12,000	--	--	--
Taiwan	12,700	6,350	5,880	9,140	4,750	4,850
Thailand	1,460	813	4,200	2,470	1,300	5,970
United Kingdom	528	354	47	53	135	13
Venezuela	178	185	355	158	162	336
Vietnam	70	34	1,370	192	90	1,670
Other	861 <sup>r</sup>	426 <sup>r</sup>	806 <sup>r</sup>	612	329	4,720
Total	85,500	47,000	221,000	84,400	44,600	150,000

<sup>r</sup>Revised. -- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Harmonized Tariff Schedule of the United States (HTS) code 2810.00.0000.

<sup>3</sup>HTS codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.

<sup>4</sup>Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 6  
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY<sup>1</sup>

Country	2001		2002	
	Quantity (metric tons)	Value <sup>2</sup> (thousands)	Quantity (metric tons)	Value <sup>2</sup> (thousands)
Argentina	263	\$161	524	\$277
Australia	--	--	2	4
Belgium	1	4	--	--
Bolivia	222	71	2,100	824
Chile	17,500	6,840	22,600	7,800
Czech Republic	--	--	1	4
France	13	43	12	23
Germany	11	6	41	24
Italy	1,290	1,390	1,140	1,390
Japan	35	84	1	9
Netherlands	--	--	5	11
Peru	3,000	1,220	2,270	873
Russia	1,650	759	8,520	3,110
Turkey	32,000	11,100	11,200	4,030
United Kingdom	22	13	17	16
Total	55,900	21,700	48,500	18,400

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>U.S. customs declared values.

Source: U.S. Census Bureau.

TABLE 7  
BORON MINERALS: WORLD PRODUCTION, BY COUNTRY<sup>1,2</sup>

(Metric tons)

Country	1998	1999	2000	2001	2002e
Argentina	279 <sup>r</sup>	245	513 <sup>r</sup>	634 <sup>r</sup>	510 <sup>3</sup>
Bolivia, ulexite	7	15 <sup>r</sup>	41 <sup>r</sup>	32 <sup>r</sup>	35
Chile, ulexite	280	325 <sup>r</sup>	338	328 <sup>r</sup>	330
China <sup>c,4</sup>	137 <sup>3</sup>	110	145	150	145
Germany, borax <sup>e</sup>	1	1	1	1	1
Iran, borax <sup>5</sup>	2	4	4	4	4
Kazakhstan <sup>c</sup>	30	30	30	30	30
Peru	22	15	9	9 <sup>e</sup>	9
Russia <sup>e,6</sup>	1,000	1,000	1,000	1,000	1,000
Turkey <sup>c,7</sup>	1,650	1,500	1,450	1,500	1,500
United States <sup>8</sup>	1,170	1,220	1,070	1,050	1,050 <sup>3</sup>
Total	4,570	4,460	4,600 <sup>r</sup>	4,740 <sup>r</sup>	4,610

<sup>e</sup>Estimated. <sup>r</sup>Revised.

<sup>1</sup>World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through May 20, 2003.

<sup>3</sup>Reported figure.

<sup>4</sup>Boron oxide (B<sub>2</sub>O<sub>3</sub>) equivalent.

<sup>5</sup>Data are for years beginning March 21 of that stated.

<sup>6</sup>Blended Russian datolite ore that reportedly grades 8.6% B<sub>2</sub>O<sub>3</sub>.

<sup>7</sup>Concentrates from ore.

<sup>8</sup>Minerals and compounds sold or used by producers, including both actual mine production and marketable products.